On a Mercury Tiltmeter and its Application

By Kennosuke HOSOYAMA

Abstract

This article describes the tilting motion of the ground observed before and after the occurrence of strong earthquakes at the observation stations near the epicenters. The instruments used in observation were the tiltmeter of the horizontal pendulum type and the mercury tiltmeter. A comparison of their instrumental functions is discussed somewhat in detail. In conclusion proof is given to the effect that both instruments may reliably be used in the observation of secular changes of ground-tilt. The characteristic tilting motion of the ground observed in connection with the occurrence of two strong earthquakes has also been fully discussed.

1. *Introduction*

Destructive earthquakes have frequently occurred in our country to the great cost of life and property. In the last ten years six great and destructive earthquakes—Tottori (September 10, 1943), Tônankai (December 7, 1944), Mikawa (January 13, 1945), Nankaidô (December 21, 1946), Fukui (June 28, 1948), and Tokachi-Oki (March 4, 1952)— were recorded with the tragic number of 9,391 dead and 25,689 seriously injured persons, not to mention the terrible losses in property. For the purpose of preventing such earthquake disasters, the following two ways should be seriously adopted and eagerly pursued: The one way is in studying theoretically and practically the construction of low cost earthquake-proof buildings, and the other is in finding some method of foretelling the occurrence of earthquakes. On the latter problem many geophysicists in our country have been exerting their efforts towards the discovery and analysis of phenomena preceding the occurrence of destructive earthquakes. As a branch of such research program the observation of earth-crustal deformation has been made in our Institute with the highly sensitive tiltmeter and extensometer at several points in our country. In the following we have reported the results of observation of the secular change of ground-tilt in connection with the occurrence of strong earthquake as observed with tiltmeters of two different types at deeply seated observation rooms.

It had previously been reported by Sassa and Nishimura 〔1951〕 and the writer 〔1952〕 that the following care should be taken in tiltmetric observation for the purpose of foretelling the earthquake occurrence:

In the first place, experience has shown that it is preferable that the instrument is set up at a deeply seated room of rock formation, the optimum depth below the ground surface being 100~300m. The reason for this is that tiltmetric observation at ground level or in a shallowly seated room of several meters is severely disturbed by the large ground-tilt caused by rainfall, sunshine and other meteorological effects. Moreover, the instrument itself is badly affected by change of room temperature. On the other hand, observation in too deep a room is also to be avoided for the reason that an enormously large earth-pressure often produces a large deformation of the room in the adit, thus rendering observation results useless. Next, the function of instrument, the effect of the foundation on which the instrument is mounted, and the peculiarity of the adit used for observation are to be carefully examined. In this paper the function of instrument is mainly discussed. The test observation on the latter two problems will be reported in near future.

With regard to the problem of the function of the tiltmeter, comparative observations by means of two tiltmeters of utterly different types set on a same foundation and in a same direction were made at several observation stations. Regarding the tiltmeter of the horizontal pendulum type, its structure and capacity were described somewhat in detail by the writer in a previously published paper [1952]. And here the function of a tiltmeter of another type (the Mercury tiltmeter) will be discussed. In the following, the Mercury tiltmeter, comparative test observations by using tiltmeters of two different types, and their practical application in tiltmetric observation are reported in sequence.

2. *The Mercury tiltmeter*

The construction of the mercury tiltmeter may be seen by referring to Figure 1 and Figure 2. It is constructed mainly of pyrex glass. Two

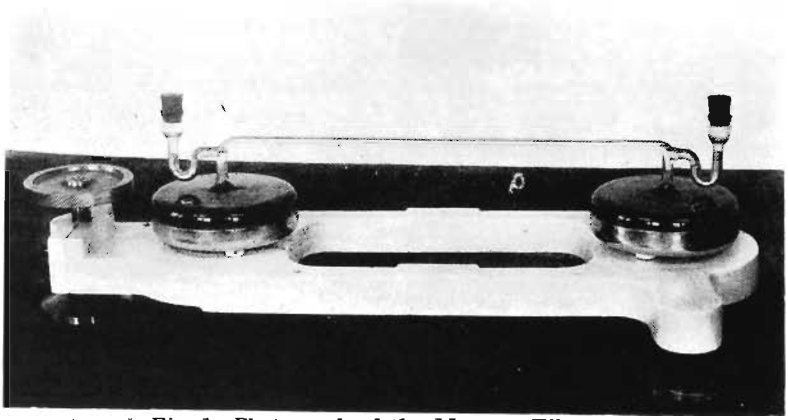

Fig. 1 Photograph of the Mercury Tiltmeter.

mercury cisterns (S) of 10 cm diameter and 3 cm length are connected by two capillary tubes (T) of 1.5 mm in inner diameter and 30 cm in length. The hatched and dotted parts in Figure 2 are filled with mercury and tinted alcohol respectively. (A) in the central part of the upper capillary tube is an air gap of several centimeters in length. The U-tubes attached to both ends of the upper capillary tube are designed to prevent the alcohol in use from evaporation. p, q, and r are mercury for blocking, liquid paraffin and .a rubber plug respectively. This glass apparatus is mounted as seen in Figure 1, on a metal frame of cast iron with three screw legs. More precisely, the base of the mercury cistern rest on three small metal projection fixed ~~motion of~~ to the metal frame. As a result of the slight motion of mercury through the lower capillary tube

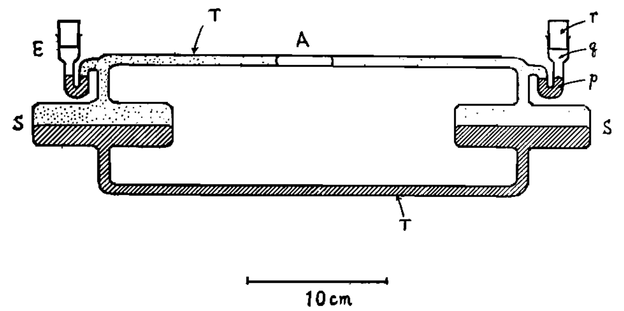

Fig. 2 Illustration of the Mercury Tiltmeter.

caused by the tilting motion of the ground, the air gap (A) is displaced in an enlarged degree by a larger ratio of the diameter of the cistern to that of the upper capillary tube. The sensitivity of the instrument is determined individually by tilting the instrument to the desired degree by rotating the control-screw of the metal frame. The mean sensitivity of 20 mercury tiltmeters available in our Institute is estimated to be about $0.44'' \pm 0.02''/\text{mm}$, which means that the air gap A displaces 2.3 mm by the ground-tilt of 1 second in angle. This figure for sensitivity may greatly be enlarged by increasing the diameter ratio between the cistern and the capillary tube.

The principle of this type of tiltmeter was introduced early by Otto Meissner [1915] and later developed by H. Haalck [1932]. But in both cases their comparative observations with another type of tiltmeter and the practical application to research observation of ground-tilt were not reported. In our case the above mentioned observations have recently been made over several years, and by them the instrumental capacity of the mercury tiltmeter has been fully examined.

3. *Test observation for comparison*

Concurrent observation with the mercury tiltmeter (M. T.) and the tiltmeter of horizontal pendulum type (H. P.) were made in a room at the ground-floor of the brick building of our Institute. Two instruments were set on a stone foundation of granite (94×61×12 cm) in the same direction and sensitivity. Both the displacement of air gap (A) of M. T. and the deflection of the mirror of H. P., caused by the tilting motion of the ground, were optically recorded on photographic paper wound around a rotating drum of 1 week-revolution. In Figure 3 an example of the tiltgram thus obtained is to be seen, and the variations recorded with both instruments show a satisfactory parallelism even in detailed points. The observation was made over a period of 7 months (June, 1951–December, 1951) and the secular change of ground-tilt recorded with both instruments have been plotted in Figure 4, their parallelism being also considered to be good. It was found in this observation that in mercury-tiltmetric observation, great care must be exercised in the following two points: One is in the generation of small air bubble in the cistern and capillary, which spoils the function of instrument and often makes the observation useless. This hitch can be removed by the carefull cleaning of the inner part of

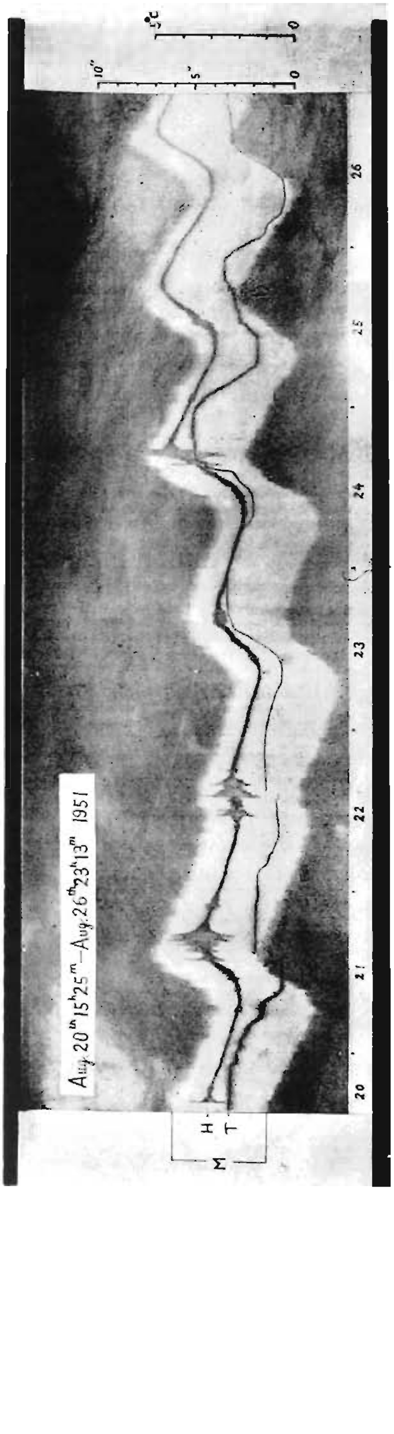

Fig. 3 Tiltgram obtained at a room of the Institute.
M, H, and T indicate the mercury tiltmeter, the tiltmeter of horizontal pendulum type and the room temperature respectively.

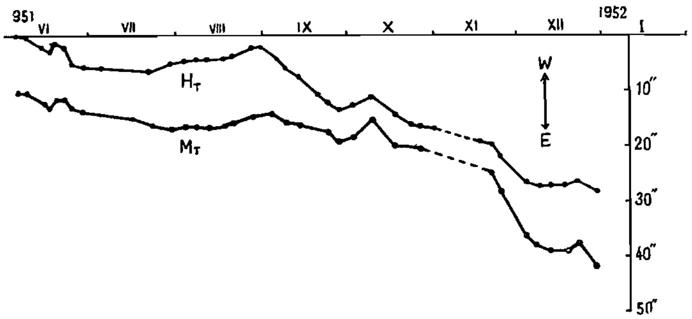

Fig. 4 Comparison of secular change of ground-tilt observed with H. P. and M. T. at a room of the Institute.

the glass tube, by purifying the mercury by chemical filtration, and by the cautious and gentle pouring of the mercury and alcohol into the glass tube through the branch tube E in Figure 2. The second point is in the change of length of the air gap (A) caused by change of room temperature. Under ordinary conditions, the air gap of 3 cm lengh, for example, changes its length in range from 0.5 cm to 7 cm in accordance with the fluctuation of room temperature of about 10°C. By experience it has been found that too short gap of less than 1 cm or long a gap of greater than 10 cm is undesirable as it often makes the observation erroneous. The optimum length in the present case is considered to be about 2~3 cm and this condition can be easily kept when the instrument is set in a deeply seated room, whose annual change of room temperature is within 1°C.

From the result of the present test observation it can safely be said that both tiltmeters of horizontal pendulum type and mercury type, under the circumstances of careful manipulation, are the most suitable means for recording the minute tilting motion of ground. In the next section their practical application will be described.

4. *Tiltmetric observations at Ogoya and Yura*

Concurrent observation with the two types of tiltmeter, H. P. and M. T., have been made at two stations of Ogoya and Yura. The former station, at Ogoya in Ishikawa Prefecture is at 136.°5E and 36°.3N, and the observation room is about 300m deep below the ground surface in the adit of the Ogoya copper mine. In geological formation, the surrounding mountains are mainly Tertiary tuff. The tiltmetric observation at Ogoya was commenced soon after the occurrence of great Fukui Earthquake of June 28, 1948, and has been continued to the present time but for a lapse of 10 months during the middle of the observation period. Concerning the tiltmetric observation at Ogoya a detailed description was given in the previous paper by the writer [1952]. The latter station of Yura in Wakayama Prefecture is at 135°.1E and 34°.0N, and the observation room is about 30m deep below the ground surface in a U-shaped adit, the main rock being Mesozoic sandstone and shale. The tiltmetric observation at Yura was commenced in November, 1951 and has been continued to the present. In both cases, the tilimeter of H. P. was optically recorded and the displacement of the air gap of M. T. was read by the reading telescope every one week.

The regular concurrent observations with both tiltmeters were commenced since June, 1952 at Ogoya and November, 1951 at Yura. And their secular variation are plotted in Figures 5 and 6. As can be seen in both Figures the secular zero-displacements bear, in general, a good resemblance to each other. The minute inconsistency appearing in these Figures may be removed by suitable adjustment of value of sensitivity (especially for M. T.), examination of personal error in reading scale-divisions for M. T. and in other various ways. Concerning the somewhat large difference for B-component at Yura, it may possibly be interpreted by the effect of the foundation. In the case of Ogoya, the two H. P. and two M. T. are all set on a square concrete block foundation (100×100×30 cm) which is firmly attached to the natural rock foundation. The effect of a concrete foundation on tiltmetric observation will be discussed on another occasion. On the contrary, in case of Yura, all the instruments are set directly on the concrete floor of adit, whose inner surface (floor, wall and ceiling) being all together cemented as one concrete tube. As the instrument for the B-component of M. T. is situated much too close to the wall, it may possibly be affected by the

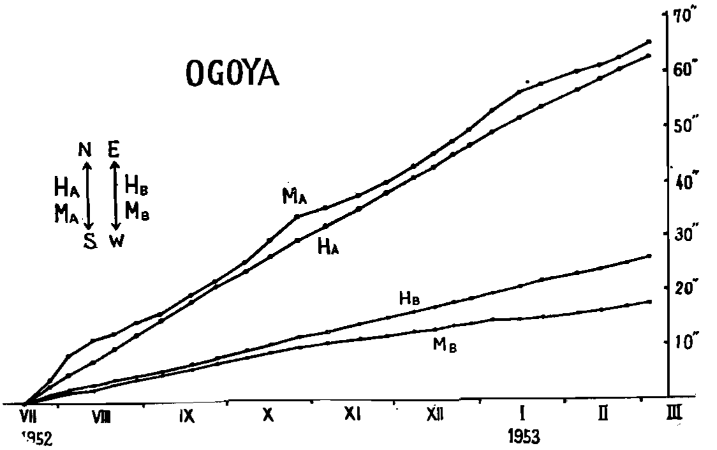

Fig. 5 Secular change of ground-tilt at Ogoya.
H_A, H_B indicate the A-and B-component of H.P. and M_A, M_B those of M. T.

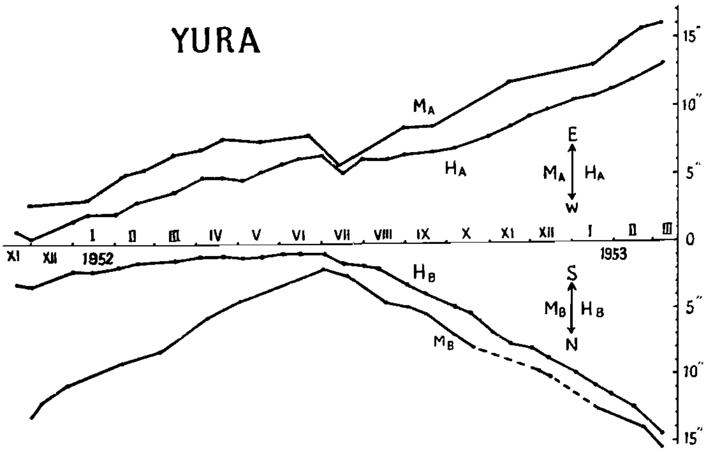

Fig. 6 Secular change of ground-tilt observed with H. P. and M. T. at Yura. H_A, H_B indicate the A-and B-component of H. P. and M_A, M_B those of M. T.

motion of the wall, if it happens that the concrete tunnel of the adit itself deforms slightly by the tilting motion of the ground. But this problem will be discussed in the near future after further observation and confirmation.

With regard to the observation at Ogoya three new points besides the present room, in various adits of depth (200m, 300m, and 300m) below the ground surface in the same mountain were selected for research observation of the particular or local deformation of each adit. At present the observation with the mercury tiltmeters set at the three points have been in operation and it is scheduled for comparative observation with H. P. and M. T. at these points, whose detailed data will be soon reported.

5. *Secular tilting motion of the ground related to the occurrence of earthquake*

Recently two strong earthquakes have occurred in the neighbourhood of the tiltmetric observation stations of Ogoya and Yura respectively. The strong Daishoji-Oki Earthquake of March 7, 1952 had its epicenter 40 km distant from Ogoya in the NW-direction. On the ground-tilt observed at Ogoya before and after the occurrence of the earthquake was full discussed in the previous paper by the writer [1952]. The strong Yoshino Earthquake of July 18, 1952 has its epicenter 60 km distant from Yura in the ENE-direction. The total energy of Yoshino Earthquake is estimated to be half that of the Daishoji-Oki Earthquake, but the shaken area humanly experienced extended to a considerable longer distance of more than 400 km from the epicenter as the hypocenter was somewhat deeply seated of about 70 km below the ground surface.

Fortunately the tiltmetric observations with H. P. and M. T. were in operation at two stations, Ogoya and Yura, when the above mentioned strong earthquakes occurred. Therefore fairly good observations on the secular tilting motion of the ground in connection with the occurrence of earthquakes were obtained at the stations in the epicentral region. In Figure 7 the tilting motion of gorund thus observed at Ogoya and

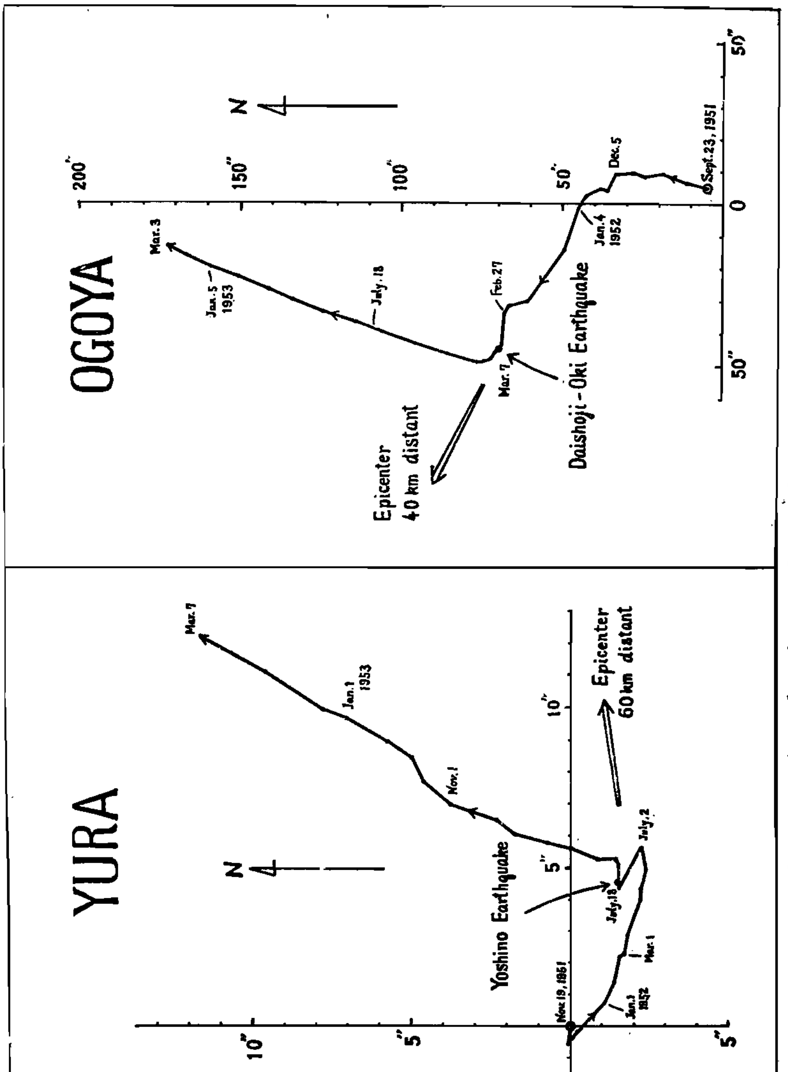

Fig. 7 Vector diagrams of secular change of ground-tilt observed at Yura and Ogoya. Single arrows show the time of occurrence of earthquake and double arrows the direction of epicenter respectively.

Yura are shown in a vector diagram, the length and direction of vector denoting the amount of ground-tilt in the angle and direction of downward-tilt of the ground respectively.

The characteristics common to both diagrams are the tilting motion of the ground towards the epicenter before the occurrence of earthquake and the tilting motion towards orthogonal direction to that of epicenter soon after the earthquake. These characteristics of the ground-tilt before and after the occurrence of earthquakes are considered to be very interesting phenomena in seismology and useful towards solving the problem of foretelling the occurrence of earthquakes. But this property was ascertained in only two cases, and so it may be doubtful that they are to be everytime observed in connection with all earthquakes. In order to solve the problem fully and to be able to give reliable predictions, the long and continued observation at many stations in the epicentral region, will be necessary.

Acknowledgements

The writer wishes to express his cordial thanks to Professor E. Nishimura for his guidance throughout this study and also to Professor K. Sassa for his frequent and valuable advice. It affords the writer a great pleasure to record his thanks for the sympathetic and kind assistance given by the following persons; the staff members of the Ogoya Mine Corporation in Ishikawa Prefecture; the staff members, especially Master K. Shinya, and the students of Taikyu High School at Yuasa in Wakayama Prefecture; the town officials of Yura, especially Chief M. Ozaki; the officials of the Department of Civil Engineering of the Wakayama Prefectural Office. The costs for the observations were covered partly by a Grant in Aid for Scientific Research from the Ministry of Education, and partly by the Research Fund of the Disaster Prevention Research Institute.

References

Haalck, H.: Ein Quecksilberneigungsmesser von hoher Empfindlichkeit, Zs. f. Geophys., 8, 1932, 256-271.

Hosoyama, K.: Characteristic tilt of the ground that preceded the occurrence of the strong earthquake of Mar. 7, 1952, Journ. Phys. of the Earth, 1, 2, 1952, 75-81.

Meissner, Otto: Neue Reduktion der Niveaumeterablesungen des hydrostatishen Nivellements auf dem Telegraphenberge bei Potsdam, Beit. z. Geophys., 14, 1915-1918, 156-186.

Sassa, K. and Nishimura, E.: On phenomena forerunning earthquakes, Trans. Amer. Geophys. Union, 32, 1-6, 1951.